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Plutonium-239 and Americium-241 Uptake by Plants from Soil

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16. ABSTRACT

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The magnitude of plutonium incorporation by the alfalfa as indicated by the concentration ratio, 2.5×10^{-6}, was similar to previously reported data using other chemical forms of plutonium. The results did indicate, however, that differences in the biological availability of plutonium isotopes do exist.

All of the species exposed to americium-241 assimilated and translocated this radioisotope to the stem, leaf, and fruiting structures. The magnitude of incorporation as signified by the concentration ratios varied from 0.1×10^{-4} for the wheat grass to 15.2×10^{-3} for the radishes. An increase in the uptake of americium also occurred as a function of time for four of the five plant species.

Evidence indicates that the predominant factor in plutonium and americium uptake by plants may involve the chelation of these elements in soils by the action of compounds such as citric acid and/or other similar chelating agents released from plant roots.

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Plutonium-239 and Americium-241 Uptake by Plants From Soil

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March 1979

PLUTCNIUM-239 AND AMERICIUM-241 UPTAKE BY PLANTS FROM SOIL

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through multidisciplinary, multimedia programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report describes the plutonium and americium transfer between soil and plant systems. The purpose is to better predict and understand the behavior of plutonium and americium in plant-soil systems. Radiobiologists should find this report of value. If further information is needed on this subject, the Pollutant Pathways Branch of the Monitoring Systems Research and Development Division, U.S. Environmental Protection Agency's, Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, should be contacted.

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas

ABSTRACT

Alfalfa was grown in soil contaminated with plutonium-239 dioxide ($^{239}PuO_2$) at a concentration of 29.7 nanocuries per gram (nCi/g). In addition to alfalfa, radishes, wheat, rye, and tomatoes were grown in soils contaminated with americium-241 nitrate [$^{241}Am(NO_3)_3$] at a concentration of 189 nCi/g. The length of exposure varied from 52 days for the radishes to 237 days for the alfalfa.

The magnitude of plutonium incorporation by the alfalfa as indicated by the concentration ratio, 2.5×10^{-6}, was similar to previously reported data using other chemical forms of plutonium. The results did indicate, however, that differences in the biological availability of plutonium isotopes do exist.

All of the species exposed to americium-241 assimilated and translocated this radioisotope to the stem, leaf, and fruiting structures. The magnitude of incorporation as signified by the concentration ratios varied from 0.1×10^{-4} for the wheat grass to 15.2×10^{-3} for the radishes. An increase in the uptake of americium also occurred as a function of time for four of the five plant species.

Evidence indicates that the predominant factor in plutonium and americium uptake by plants may involve the chelation of these elements in soils by the action of compounds such as citric acid and/or other similar chelating agents released from plant roots.

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The author would like to express his appreciation to Dr. O. G. Raabe and Dr. R. O. McClellan of the Inhalation Toxicology Research Institute, Lovelace Foundation, for providing the plutonium-239 dioxide microspheres used in this study. Also, to Mr. C. Feldt and Mrs. R. O. Houston for their support and work during this investigation.

INTRODUCTION

Many of the longest lived radioactive pollutants being released into our environment are the transuranic elements. Jacobs and Gera (1969) projected that the activity of a small number of these elements and their decay products from United States sources alone would exceed 1,000 megacuries by the year 2020. The anticipated production, use, and release of most transuranic elements into the biosphere during periods of atmospheric nuclear testing and by the expanding nuclear power industry have prompted the need for assessing their behavior in biological systems.

Of the transuranic elements used in the nuclear industry, the highly radioactive plutonium isotopes are generally considered to be of primary importance. Of the large number of plutonium isotopes used and produced, plutonium-239 is, as summarized by Mullen and Mosley (1976), the isotope most utilized. One means by which plutonium-239 is produced is by the irradiation of uranium-238 in nuclear reactors.

In addition to the concern caused by the possible environmental impact of plutonium-239, the scientific community has become increasingly aware of the environmental consequences of the formation and release of americium into the biosphere. Of the 12 americium isotopes, americium-241 is generally considered to present the most serious hazard. This isotope enters the environment primarily as a decay product of plutonium-241, which is released into the biosphere as a by-product of both the nuclear testing program and the nuclear power industry.

Reviews of the pertinent literature concerning the uptake and translocation of plutonium-239 and americium-241 by plants have been completed by Mullen and Mosley (1976), Price (1973), Frances (1973), Romney and Davis (1972), Brown (1976), and Bernhardt and Eadie (1976). These reviews have shown that these two isotopes do accumulate in both the plant and edaphic portions of our environment. They also appear in a variety of chemical forms and will accumulate in one of the many trophic levels of a biological system. Although identification of both the physical and biological parameters for assessing the amount of their assimilation by plants via a soil rooting media is limited, the foregoing reviews do show that their movements are, in general, very slow. As reported by Price (1973), the final assessment of environmental impact will show that pollutants such as plutonium and/or americium which have long residence times will increase in relative importance with time, especially in areas where they are uncontained within the biosphere.

In most plant kinetics studies, the americium and/or plutonium have been uniformly mixed in the soil rooting media. As a result, the data from these experiments would not necessarily correlate with data collected from

vegetation growing in soils where the plutonium is deposited on the soil surface. Investigations by Romney et al. (1970) have indicated that transuranic elements are normally quite immobile and tend to remain in the upper few centimeters of the soil; therefore, they are not readily available for plant assimilation. Nevertheless, the results of laboratory investigations where plutonium and americium are uniformly mixed in the rooting media are valuable in understanding the contamination of cultivated vegetation grown on plowed lands and also in the identification of the mechanisms which control their uptake and distribution in plants.

Public awareness concerning the possible biological impact of plutonium has increased because of its anticipated production and use in breeder reactors (Pigford, 1974) and as fuel for the numerous nuclear power systems. Also, the projected impact of americium as suggested by Poet and Martell (1972) and Major et al. (1974), and the results of investigations by a small number of researchers such as Dr. O. G. Raabe and his research associates in 1973, were instrumental in the initiation of this investigation.

This study was designed to determine the extent and magnitude of plutonium-239 and americium-241 assimilation by plants growing in soils. It was also conducted to obtain additional data concerning the isotopic differences in plant uptake between plutonium-238 and plutonium-239 oxides. The initial investigation which dealt with the plant assimilation of plutonium-238 oxide was previously reported by Brown and McFarlane (1977).

CONCLUSIONS

The results of this study have shown that plutonium in the form of plutonium-239 dioxide is taken up and translocated to the aerial portions of the commonly cultivated plant species, alfalfa. Based on the concentration ratios, the amount of plutonium assimilated and translocated by this plant species appears to be in about the same proportion as the incorporation of other chemical forms of plutonium by a variety of other plants, including both aquatic and terrestrial species. However, there do appear to be differences in the amount of plutonium assimilated between different isotopes. For example, previous studies by Brown and McFarlane (1977) using identical plant species grown under nearly identical physical and environmental conditions showed that plutonium-238 dioxide is more readily available for plant uptake.

The long-term exposure of the alfalfa did not cause any increase in the concentration of plutonium in the plant tissue, even though the root mass increased. This increase in root mass would normally enhance the probability of a contaminant assimilation as the chance of physical contact with the soil-borne pollutants would increase. Since the behavior of $^{239}PuO_2$ in soils, as indicated in this study, parallels other chemical forms of plutonium as far as plant assimilation, the rate and means of uptake are probably determined by the effect of root exudates. A number of investigators, including Romney et al. (1970), Schultz et al. (1976a), Rhodes (1957), and Price (1972), have indicated that the biological availability of plutonium is largely governed

by its solubility and also by the numerous chemical reactions which occur in soils.

Americium in the form of $^{241}Am(NO_3)_3$ was also shown to be taken up and translocated to the aerial organs of five species of commonly cultivated crop and pastureland plants. The amount of americium assimilated and translocated by these plant species appeared to be similar in magnitude to that assimilated by other plant species under a variety of conditions.

The long-term exposure of these species did show an increase in the concentration of americium in the plant tissues. This behavior, of americium availability, similar to the biological availability of plutonium over a period of time as reported by Romney et al. (1970), is governed by its solubility and by the chemical reactions occurring in the soils.

The reactions which are enhanced by the soil microflora, as reported by Au (1974), involve and affect soil pH and the rates of natural and/or induced chelation. As such, the effects of chelation, additions of various soil dressings, and changing soil pH on the availability of plutonium and americium transfer from soils to plants are important factors that merit additional study.

METHODS AND MATERIALS

As previously stated this investigation was designed to determine the extent and magnitude of plutonium and americium assimilation by plants growing in soils. The chemical form and the isotope of plutonium selected for this study was $^{239}PuO_2$. It was selected for investigation primarily on the basis of observations made and reported by Dr. O. G. Raabe and his research associates in 1973. The chemical form and isotope of americium used was $^{241}Am(NO_3)_3$.

Monodisperse $^{239}PuO_2$ particles were obtained from the Inhalation Toxicology Research Institute, Lovelace Foundation, located in Albuquerque, New Mexico. The particles had a geometric mean diameter of 0.44 micrometers (μm). They were stored dry on a stainless steel foil inside a screw-capped plastic centrifuge tube. The amount obtained for this study was 100 microcuries (μCi). The $^{241}Am(NO_3)_3$ was obtained from a commercial source and consisted of 3.0 millicuries (mCi) in a solution of 0.5 M HNO_3.

The soil selected for the rooting media for both isotopes was a silty loam consisting of 57.6 percent sand, 36.8 percent silt, and 5.6 percent clay. It had a pH of 7.9 and a cation exchange capacity of 12.23 milliequivalents (meq)/100 g. The soil, which had been sieved through a 0.417-millimeter (mm) standard seive, and the two isotopes were shipped to the Nuclear Chemistry Division at the Naval Weapons Center, White Oak, Maryland, for mixing.

The initial procedure for preparing the plutonium-239 rooting media was to remove the particles from the foil and suspend them in a suitable solution. The procedure used was previously described by Raabe et al. (1975) and used

by Brown and McFarlane (1977). Basically, this method involves adding 50 ml of a 0.02 percent surfactant solution (Triton® X-100) to the centrifuge tube, thereby submerging the stainless steel foil. The centrifuge tube is then placed into an ultrasonic water bath to dislodge the plutonium particles from the stainless steel foil. After a 4-hour period of ultrasonic agitation, the soil was removed.

Because of the necessity of dry-mixing to obtain a homogenously mixed rooting media, the surfactant solution containing the $^{239}PuO_2$ particles was added to a slurry of talc, $H_2Mg_3(SiO_3)_4$. The $^{241}Am(NO_3)_3$ in nitric acid was also added to a separate talc slurry. The talc, which readily absorbed the liquid, was then dried under an infrared lamp. These brittle talc conglomerates were then transferred *in toto* to a 30-liter capacity Patterson-Kelley twin shell® blender where the mixing action of the soil particles broke down the talc conglomerate into a fine powder. The two isotopic-talc conglomerates were mixed separately, each with a different batch of soil.

The length of blending time to obtain a homogenous soil mix had been previously determined by using $^{238}PuO_2$ tagged with ytterbium-169. The ^{169}Yb concentration was determined from aliquots of soil collected from the blender over a 20-hour period. The precise methods and procedures used in the soil mixing techniques were reported by Brown and McFarlane (1977). After mixing, the plutonium soil mix was divided into 3 nearly equal portions and the americium soil mix into 16 nearly equal portions. Each portion was then placed into a 1,000 ml plastic bottle, put into an appropriate shipping container and shipped to the U.S. Environmental Monitoring and Support Laboratory in Las Vegas.

The transfer of the potting soil into specially designed 127-mm greenhouse pots was completed at the Las Vegas Laboratory. This procedure was accomplished in a standard radiation glovebox. Before transferring the soil, 25 g of vermiculite were added to each of the 19 plastic bottles to prevent excessive soil compaction during plant growth. The bottles, which contained approximately 860 g of the plutonium and americium contaminated soil, were capped and then rotated by hand for approximately 5 minutes to mix the vermiculite into the soil. After mixing, all the soil from one of the bottles was poured into one of the greenhouse pots. This procedure was duplicated until all 19 pots were filled. The three pots containing the plutonium were transferred from the glovebox into a self-contained environmental growth chamber. The remaining 16 pots containing the americium were transported from Las Vegas to the greenhouse facility located at the U.S. Environmental Protection Agency's experimental farm on the U.S. Department of Energy's Nevada Test Site.

As previously stated, the pots were specially designed as shown in Figure 1. The pots were designed to contain the plutonium and americium over an extended period. To prevent loss, a nylon reinforced Acropor® filter with a pore size of 0.20 μm was cemented over the drain holes. To protect the Acropor® filter from damage by roots and to help prevent it from being plugged by soil particles, a Microsorban® filter was placed in the bottom of the pot to act as a prefilter. To reduce the loss of the plutonium and

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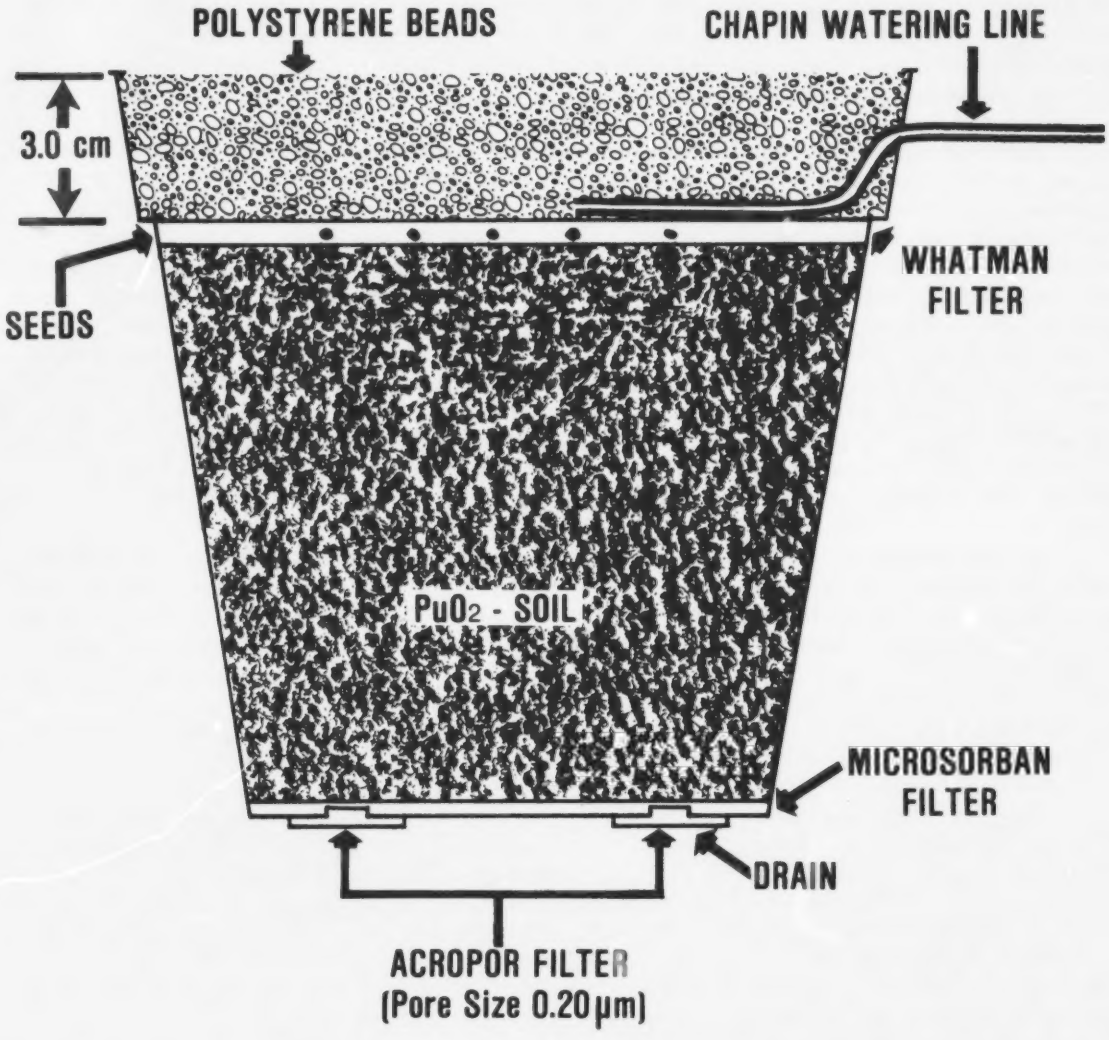

Figure 1. The design of the 127 millimeter plastic greenhouse pots used to hold the plutonium-239 and americium-241 contaminated soils.

americium by upward migration via capillary action, the soil surface was covered by a Whatman® filter that had been impregnated with seeds. The Whatman® filter was then covered with a 3.0-centimeter (cm) deep layer of 0.3-cm diameter polystyrene beads.

Further safety precautions included the construction of a fiberglass-lined wooden tank measuring 115 x 115 x 18 cm which was placed in the growth chamber and greenhouse to hold the pots. Once the pots were placed in the tank, handling of the contaminated material was eliminated except during harvesting. Also, an automatic irrigation system was designed. Features of this system included the recycling of the evapotranspired water, exterior controls, and a safety float installed in the fiberglass-lined tank. The safety float was installed to shut off the pump, timer, and solenoid if excessive amounts of water occurred in the tank. To ensure a fairly even distribution of water to each pot, manifolds were used, each distributing water to a preselected number of pots. Each pot was irrigated with approximately 180 ml of water per day. Plant nutrients were provided by irrigating once every 6 weeks with a modified Hoagland solution as described by Berry (1971).

An air sampling system was constructed as a safety precaution to sample both the greenhouse and chamber air. The air was pumped from the chamber and greenhouse through a Millipore® membrane filter having a pore size of 0.1 µm and then exhausted back in the greenhouse and growth chamber. The air was sampled at a flow rate of 12 liters per minute (lpm). This sampling was conducted prior to entering the growth areas. After the decay of naturally occurring radon, the filter was counted to determine if any of the plutonium and/or americium had become airborne.

The environmental growth chamber used for the plutonium study was specially constructed to conduct soil-plant kinetic studies involving selected chemical forms of radioisotopes. As a result, the chamber was virtually airtight with all the controls on the exterior. Throughout this investigation a chamber photo-period of 16 hours was maintained. The light-dark temperatures were kept at 25° C and 20° C, respectively. Carbon dioxide (CO_2) was automatically injected into the chamber atmosphere to maintain a uniform daytime concentration of 350 parts per million (ppm).

The greenhouse used for the americium study was fairly small, measuring approximately 3 meters long, 2 meters wide, and 2.5 meters in height. Light banks plus two portable heating and cooling units were installed in the greenhouse prior to the initiation of this study. The photo-period and the light-dark temperatures were kept nearly identical to those in the growth chamber.

SAMPLE COLLECTION AND ANALYTICAL PROCEDURES

Soil samples were collected from the plutonium-soil pots 2 days after placement into the growth chamber, and from the americium-soil pots 1 day after placement into the greenhouse. This delay was to ensure that all of the soil in the pots was damp due to irrigation. Samples were collected by

inserting a 10-cubic centimeter (cm^3) disposable syringe, which had the bottom (needle attachment) end cut off, into the soil. The syringe was then withdrawn containing a 7- to 10-g (dry weight) core of soil. Using the syringe plunger, the soil core was removed and placed into an aluminum can. To avoid cross-contamination, 19 different syringes were used. The wet weight of each soil sample was determined and then they were dried in an oven at a temperature of 100° C to determine the dry weight. The cans were then sealed and sent to the Eberline Instrument Laboratories located in Albuquerque, New Mexico for analysis.

The initial plant samples were collected from the plutonium and americium soil pots 51 and 52 days, respectively, after planting. They were collected by clipping with scissors and then were placed into a small preweighed paper bag. The samples were weighed and then dried at a temperature of 75° C. The bags were individually sealed in aluminum cans and sent, similar to the soil samples, to the Eberline Instrument Laboratories for analysis. These samples were not removed from the paper bag but were dissolved *in toto*. This procedure eliminated additional handling of plant material and therefore increased the precision of analysis. No attempt was made to separate the various plant organs in the plutonium portion of this investigation. It was, however, done in the americium portion; i.e., stems, leaves, and fruit were collected and analyzed separately.

Basically, the analytical technique for the plutonium analysis included decomposition of the soil and plant material by potassium fluoride fusion and/or acid dissolution. After decomposition, plutonium-236 was added as a tracer followed by the separation of the plutonium by ion exchange or solvent extraction. The plutonium was electroplated and then counted by alpha spectroscopy.

The analytical methods for the americium analysis included dissolving the samples in nitric and hydrofloric acids. Prior to decomposition, americium-243 was added as a tracer followed by two successive solvent extraction steps and one cation exchange resin step. The americium was then electroplated and counted by alpha spectrometry.

RESULTS AND DISCUSSION

Plutonium

Alfalfa, *Medicago sativa*, was planted in each of three pots. As stated, the soil had been mixed in one batch and then divided into three portions. The plutonium-239 concentration of the soil was 29.7 ± 2.1 nCi/g. This calculated concentration represented the mean and standard deviation of three soil analyses from the three soil aliquots sampled from each pot.

Stem and leaf tissues were collected over an 8-month period representing 237 days. After clipping, the alfalfa was allowed to regrow. Reharvesting occurred 6 additional times thereafter, usually within a 31- to 38-day growth period.

Investigations involving the transfer of plutonium from soils to plants via root assimilation have shown that a large concentration ratio (CR)

$$CR = \frac{\text{concentration in the plant nCi/g dry}}{\text{concentration in the soil nCi/g dry}}$$ exists. The alfalfa concentration ratio is shown in Table 1.

TABLE 1. PLUTONIUM CONCENTRATION RATIO FOR ALFALFA PLANTS GROWN IN SOIL CONTAMINATED WITH $^{239}PuO_2$ SPHERES

Soil Concentration (nCi/g)	Concentration Ratio ($\times 10^{-6}$)
29.7 ± 2.1*	2.5 ± 1.5†

*Standard deviation, s, of three soil analyses.
†Standard deviation, s, of seven concentration ratios.

The magnitude of plutonium uptake by alfalfa was greater during the first half of this investigation, 0 to 104 days, than during the latter portion, 105 through 237 days. The amounts of ^{239}Pu assimilated per gram of dry tissue during the first and second portions of this study were 0.2 and 0.02 picocuries (pCi), respectively. This is surprising in view of the fact that the growth (dry matter) of the alfalfa increased with each successive cutting. This increase in tissue is evidence that the rooting system was increasing in size, thereby, coming in physical contact with more potentially absorbable plutonium. A proportionate increase in plutonium uptake was associated with this increased plant growth rate. However, the concentration in the plant tissue remained unchanged; in fact, it decreased somewhat during the latter portions of this study.

Evidence indicates that the absorption of plutonium by plants is perhaps dependent upon the release of a particular compound or upon the formation of some chemical complex at the root surface. This could explain, in part, the lack of plutonium assimilation by these plants over the 237-day growth period. In another experiment conducted by Brown and McFarlane (1977) similar results were obtained. They reported that alfalfa grown in soils contaminated with spheres of $^{238}PuO_2$ and cropped over a 358-day growing period did not show any significant increase in plutonium assimilation with time. They hypothesized that plutonium solubility in soils, water movement in plants, growth rate, and root contact potential appear to have little impact on plant assimilation of plutonium. The results of this study and the previous one conducted by Brown and McFarlane (1977) suggest that chemical reactions occurring at the root surfaces predominate the kinetics of plutonium uptake and translocation in plants. Plants are known to exude organic compounds such as citric and humic acids which form strong chelates with plutonium. Based upon the results of this study and the findings of other investigators (Romney et al., 1970), it appears that the release of citric acid and/or other similar chelating compounds may be responsible for plutonium uptake.

Further evidence supporting this hypothesis is that Francis (1973) summarized the available literature and reported that plutonium concentration ratios generally fall between 10^{-4} and 10^{-6}. This large discrimination against plutonium absorption by plants was confirmed by Hansen (1975) and again summarized by Bernhardt and Eadie (1976). In addition to the studies cited by these investigators in which many different chemical forms and both ionic and chelated-complexed plutonium were applied to the rooting media, the same general magnitude of plutonium assimilation by plants was reported by McFarlane et al. (1976) following a root exposure to plutonium in solution cultures.

A number of studies, such as those conducted by Raabe et al. (1973) indicated that plutonium isotopes vary in solubility. They reported that during an in vitro study using plutonium-238 and plutonium-239 dioxide particles exposed to a serum stimulant, similar in chemical composition to blood serum, the solubility rate was about two orders of magnitude higher for the plutonium-238 dioxide particles than for the plutonium-239 dioxide particles. If this solubility difference between the two isotopes occurred during other biological reactions, environmental contaminant priorities would have to be selected and based upon additional criteria.

To furnish additional data concerning the possible differences existing between the solubility of plutonium-238 and plutonium-239 in plant-soil systems, this investigation was conducted in many aspects identical to the previously mentioned study by Brown and McFarlane (1977). The mixing procedures, plant species, soil, and the environmental conditions were the same for each study. Plutonium-238 dioxide particles measuring 0.32 μm in diameter were used for the previous investigation. In addition, the $^{238}PuO_2$ soil concentration was slightly lower, 23 ± 3 nCi/g. Even though a direct comparison between the two isotopes cannot be made because of the variation in particle size, differences in plant assimilation of the two isotopes were evident. Based upon the concentration ratios during the initial growing period, 51 days for the $^{239}PuO_2$ exposure and 55 days for the $^{238}PuO_2$ exposure, $4.0 \pm 2.7 \times 10^{-6}$ and $2.0 \pm 1.1 \times 10^{-4}$, respectively, the plutonium-238 incorporated into the aerial plant portions exceeded the amount of plutonium-239 assimilated by 50 times. This trend continued through both studies. For example, at the end of the 237-day growing period for the plutonium-239 study, which can be correlated with a 242-day growing period for the plutonium-238 study, the relationship between the concentration ratios was nearly identical, 6.7×10^{-7} and 3.0×10^{-5}, respectively, to those ratios calculated for the 51- and 55-day exposures.

Americium

Five plant species, alfalfa, radish, *Raphanus sativus*, rye grass, *Secale cereale*, wheat, *Triticum sp.*, and tomatoes, *Lycopersicum sp.* were planted in the americium-241 soil mix. As previously described, the americium-241 contaminated soil was divided into 16 nearly equal portions and then transferred into 16 greenhouse pots. Three of the pots were planted with alfalfa, three with radish, three with rye, and three with wheat. The remaining four pots were planted with tomatoes. The americium-241 concentration in the soil was

189 ± 31 nCi/g. This calculated concentration represented the mean and the standard deviation of 16 soil analyses from 15 soil aliquots sampled from each pot.

Stem leaves, and fruiting structures were collected over an 8-month period representing 236 days. The initial plant sampling occurred 52 days after sowing. Three species, alfalfa, rye, and wheat, were allowed to regrow after each harvest. The radishes were replanted once following the initial harvest. Investigations concerning the assimilation of americium by plants via root uptake similar to those conducted on plutonium incorporation have shown concentration ratios that vary between 10^{-1} and 10^{-7}. This large variation has been shown to be due in part to differences in soil pH, and the addition of various soil dressings such as lime and the chelating agent diethylenetriaminepentaacetic acid (DTPA) (Wallace, 1974 and Schulz, 1977).

The americium-241 concentration ratios for the five plant species at each harvesting period are shown in Table 2. Because of the fairly long duration of this study, indications of increased uptake over time were observed. Figure 2 shows the concentration of americium-241 in the stem and leaf tissues of the alfalfa and tomato plants, and Figure 3 shows the americium concentration in the rye and wheat grasses. As is shown on these two figures, the amount of americium-241 assimilated by these plants at the end of the growing period for all four species was of the same general magnitude. Perhaps the most interesting observation is that even though all four species showed an increase in americium uptake, the rate of assimilation was greater in the grass species than in the alfalfa and tomato plants.

The maximum amount of americium-241 taken up and accumulated in the radishes varied between a high of 288.2 pCi/g (dry) and a low of 50.7 pCi/g (dry). The maximum concentration in the radishes occurred during the initial 52-day growth period. The decrease in the amount of americium assimilated during the second planting and growth period, which was 86 days, cannot be explained.

TABLE 2. CONCENTRATION RATIOS FOR FIVE PLANT SPECIES GROWN IN SOILS CONTAMINATED WITH AMERICIUM-241 ($\times 10^{-4}$)

Harvesting Period (Days After Planting)	Plant Species				
	Alfalfa	Radish	Rye	Wheat	Tomato
52	1.9±0.6	152.0±30.0	3.5±1.9	0.1±0.0	---
75	1.6±0.3	---	2.2±0.6	4.5±2.3	1.1±0.6
102	1.2±0.3	---	2.9±1.8	3.6±1.3	0.7±0.2
125	---	---	---	---	0.6±0.5
138	2.3±0.4	2.7±0.4	0.6±0.2	---	1.4±0.7
145	1.1±0.3	---	1.7±0.4	7.0±2.2	1.1±0.9
188	3.2±0.5	---	---	---	---
216	35.0±22.0	---	8.1±4.1	8.2±4.3	21.0±4.0
236	11.0±6.0	---	9.7±6.5	---	---

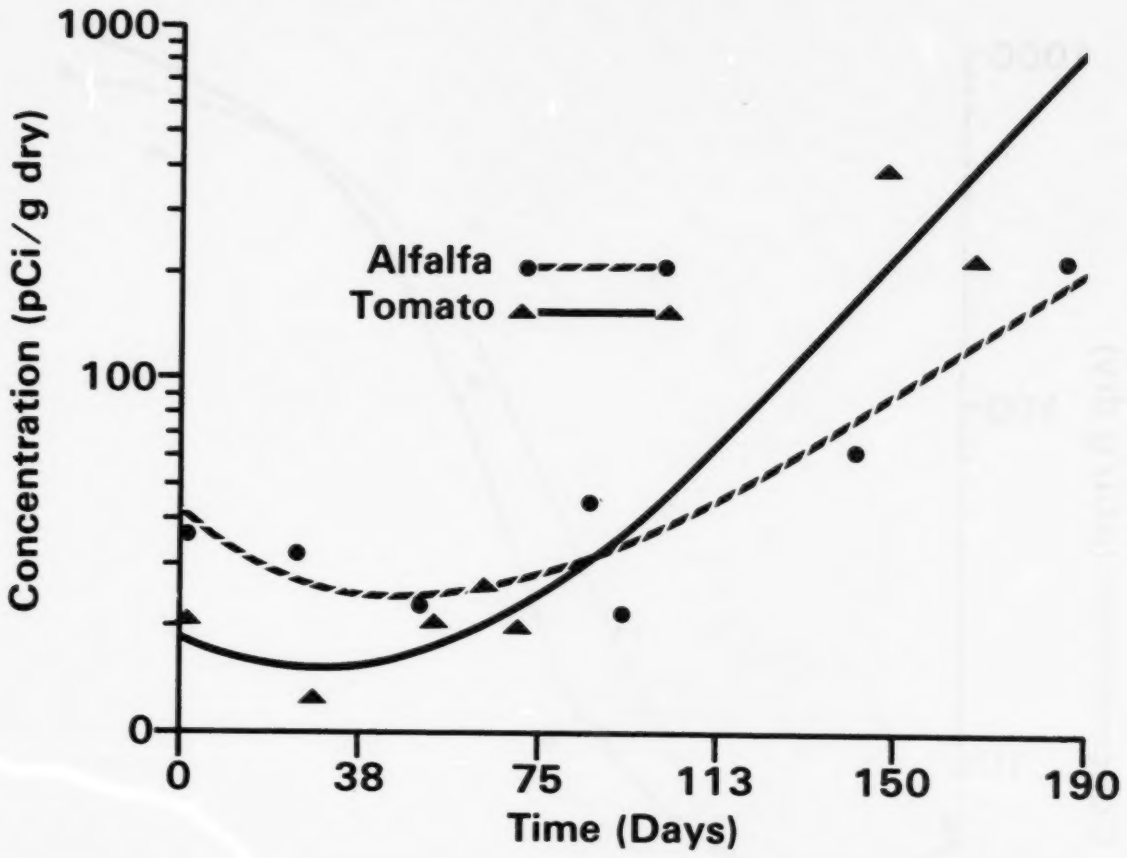

Figure 2. Concentration of americium-241 in the stem and leaf tissues of alfalfa and tomato plants.

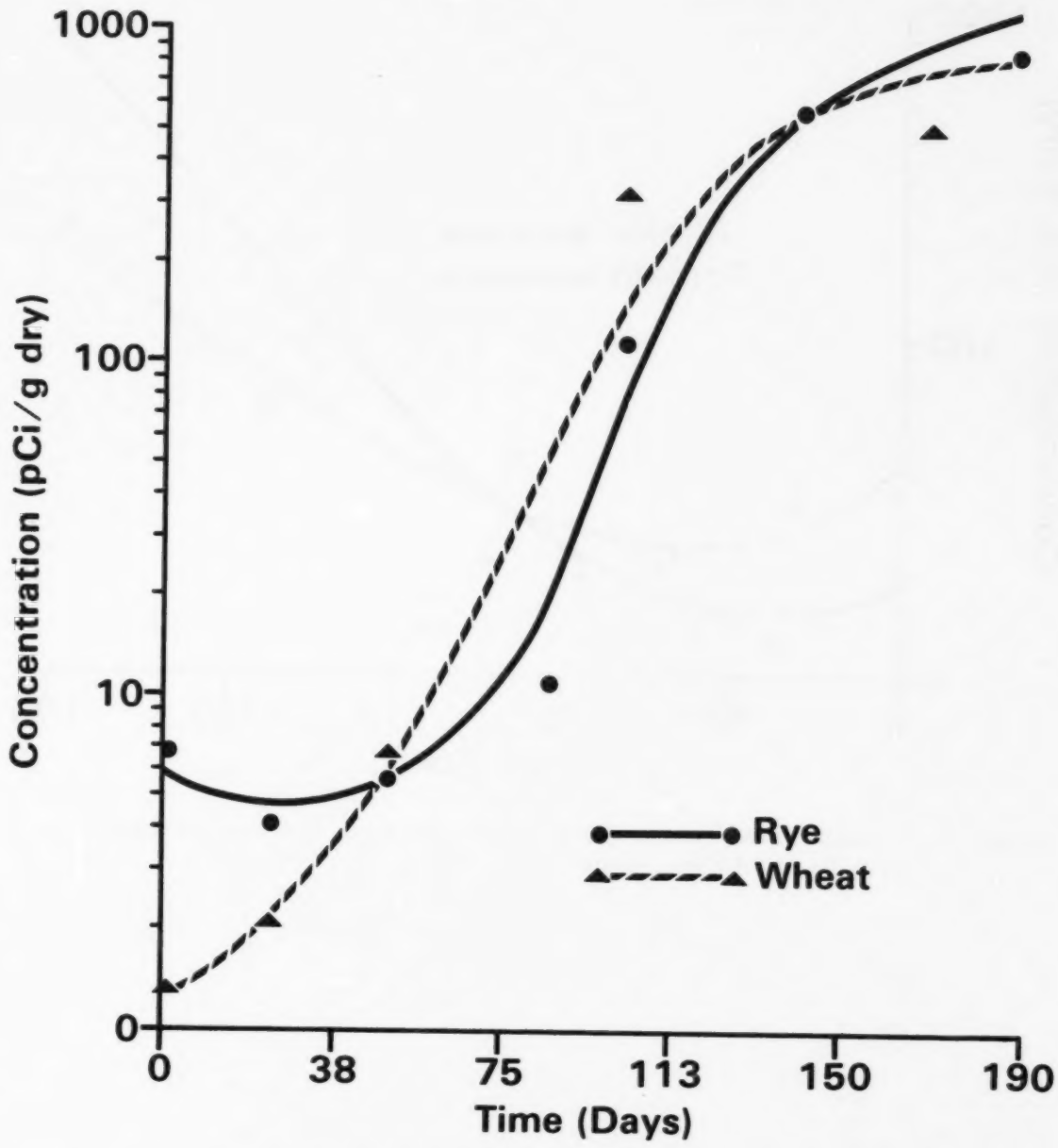

Figure 3. Concentration of americium-241 in the stem and leaf tissues of rye and wheat grass.

An increase in americium uptake exhibited by four of the plant species as a function of time is perhaps associated with a number of parameters. The most obvious one is the increase in root mass which was verified by an increase in the growth rate (dry matter synthesis) of the stem and leaf tissues, which occurred with each successive cutting. Other parameters affecting americium solubility and uptake could have been the exuding of various organic compounds by the plant roots such as citric and humic acids which may form strong chelates with the americium. These processes, in addition to the affects of various chelating agents and other soil dressings on the biological availability of selected transuranic elements, have been previously reported by Wallace (1974), Romney (1970), Au (1974), and Schulz (1977).

Americium was also translocated to the fruiting structures of each species. The fruiting structures of the grass species accumulated the greatest amount of americium-241 when compared to the concentration in the stem and leaves. The percentage compositions of the fruiting structures of the rye and wheat grasses when compared to their respective stem and leaf tissues were 9 percent to 91 percent and 46 percent to 54 percent. The high ratio, 46 percent of the americium-241 accumulated by the wheat grass heads, cannot be explained as none of the other species exhibited this trait. Harvesting of the fruiting structures of these two grass species was completed only one time during this investigation, as such, trends of americium translocation with time could not be made.

Tomatoes were harvested and analyzed three separate times during this study. Table 3 shows the amount of americium-241 assimilated by the stem and leaf tissues and translocated to the tomatoes at each collection period. Also shown is the percentage composition provided by each portion.

TABLE 3. AMERICIUM-241 CONCENTRATIONS IN THE STEM AND LEAF TISSUES AND IN THE FRUITING STRUCTURE OF TOMATO PLANTS

Growing Time (Days)	Americium-241 pCi/g (dry)		Percentage Composition (%)
	Stem and Leaves	Fruit	
52	20.5±0.0		80
		5.2±1.6	20
149	383.4±61.0		92
		31.3±17.7	8
164	267.7±60.4		96
		9.2±3.4	4

As shown in Table 3, the percentage translocated to the fruit was greater during the initial growing period than during the subsequent growing and harvesting periods. The apparent decrease of americium translocated to the tomatoes when compared to the stem and leaf tissues during each growth and harvesting period cannot be explained. The magnitude of americium incorporation into the fruit does, however, compare with other reported values (Schulz et al., 1976b; and Romney et al., 1976).

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